12 Caving

Chapter Summary
Caving damages a specialised, rare, and delicate environment which can never recover. The aim is to minimise this mostly unintentional damage. The number of cavers is small but they can damage caves in many ways: the geological environment, cave fauna and flora which is specialised and often endemic. Bats are important and have suffered in North America from white nose syndrome, partly spread by cavers. Many potential management strategies for caves exist including cave plans, conservation codes, and National Conservation policies. Controlling access can be important and there are access agreements, zero, restricted or periodic access, booking systems, gating, sacrificial caves, zoning in caves, cave exploration policies, and cave fauna management, including building artificial bat caves. Education for cavers includes minimal impact codes, websites, leader and instructor schemes, involvement in cave conservation planning, and cave adoption schemes and alternatives to caving, such as the use of mines and artificial caves.

12.1 Introduction and Numbers Involved in Caving

Caving as an activity is a specialist outdoor pursuit that is practised by a relatively small number of practitioners. Although it is possible to subdivide the activity into several types: speleology (the science related to caves), spelunking (US term), and caving (the recreation activity related to caves) and potholing (for caving where there are vertical pitches), we will consider all three as one in this chapter and call the activities caving. There is a further category to be considered which is the tourist show cave. The numbers involved in the activity are difficult to ascertain but the following are some minimum estimates: In Britain the numbers caving in 1971–1972 were estimated at a conservative figure of 16,000–17,000 with 400 caving clubs (Wilmut 1972). By 1990 the numbers caving each year had risen to 30,000 based on the total members of caving clubs (Ford 1990). As an indication of the importance of caving as an outdoor recreation activity though in the report by Gordon et al. (2015) caving is not considered in the section on Outdoor Activity participation. In the USA in 2012 caving did not appear in the top 25 outdoor activities, and out of 43 activities in terms of outdoor participation it does not appear (Outdoor Foundation 2016). In the USA the figures are surprisingly

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low with the National Speleological Society (NSS) having around 2000 new members in 1950, 2100 in 1980, 4900 in 2000, but with the figure total down to 9256 in February 2016. In the USA each member belongs to local chapters known as Grottos. The National Survey on Recreation for the period 2005–2008 shows that the total US participants in caving were 9871, an 8.9% positive change as compared to the period 1999–2001. During 2005–2009 these figures were 10,400, a 4.4% increase, whilst the participation days were 19.5 million, a 2.4% positive change (Bowker et al. (2012); according to Cordell et al. (2008) and Cordell (2012) the total annual participation days were 21.6 million in 2005–2008, a 3.3% positive change. The projected backcountry outdoor recreation participation rates from 2008 to 2060 and under the category of challenge (mountain climbing, rock climbing, and caving) the participants in 2008 were 25 million, but by 2060 this figure was predicted to change to anywhere between 38 and 48 million, with an average change of plus 19 million. The number of participation days in 2008 was 121 million for these activities, but by 2060 this figure is estimated to increase to between 178 and 219 million, with an average change of 86 million. The figures vary because of the estimates of population growth used, income growth, and the various effects of climate change. However, based on the figures for caving noted earlier, cavers make up a small percentage of participants in these three challenge activities.

In response to the question "How many cavers are there in Europe?," the Association Hommes des Cavernes (2015) estimated a total figure of 40,300 based on figures from national federations who are members of the European Speleological Federation, with France having the largest number.

The cavers in New Zealand belonging to the New Zealand Speleological Society currently stands at around 300 members, whilst in Australia the Australian Speleological Federation represents the interest of 28 caving clubs and has over 700 members. Whilst the membership might only be a conservative estimate of the numbers actively caving it gives a good indication of the small total numbers involved. The bigger problem might be, however, that the small number of cavers not members of clubs may well cause a disproportionately greater amount of damage to caves and because of the high turnover of participants and the fact that at any given time period the numbers caving consist of a very high proportion of relative beginners. This is especially so when one considers the numbers of these beginners who are taken into caves from outdoor centres for adventure experiences with perhaps greater numbers than we would ideally recommend in a group and hence the greater difficulties of controlling that group. Against this view would be the fact that the leaders of these groups are generally well qualified and probably use easy, popular caves considered as sacrificial.

Recreational cavers can be subdivided into individuals and small groups using caves for outdoor pursuits and exploration; outdoor centres using caving as an activity or for educational purposes; and caving clubs using caves for exploration. Speleologists include geologists, mineralogists, geomorphologists, hydrologists, biologists, and archaeologists simply because caves are repositories for a wealth of scientific knowledge about landscape development, specialised forms of mammals, fish, and insects and how man and animals have evolved and lived at various time periods. The include Minchin Hole on Gower, Wookey Hole and Gough's Cave (Cheddar), the Buckfastleigh caves (Devon), Pontnewydd and Clwyd caves in North Wales in Britain; the important South African hominid and animal bone caves (Fig. 12.1) at the Cradle of Humankind World Heritage site in Gauteng Province (South Africa), which have famous cave sites for Australopithecus, *Homo erectus*, *Homo naledi*, and *Homo sapiens sapiens* fossils; Natural Trap Cave (Wyoming), Boodie Cave, Barrow Island off the west Australian coast which was first occupied by man 51,100–46,200 years ago and the important European cave sites like Altamira in Spain and in the Dordogne in France.

There are many commercial show caves too which can have detrimental effects as we will see later. Occasionally caves are used for industry and with specialised forms of agriculture such as mushroom farming, fish breeding, and

Fig. 12.1 *Homo naledi* bones from Rising Star Cave, part of the Cradle of Humankind World Heritage site about 50 km north-west of Johannesburg. Found by recreation cavers in 2013 and first described in 2015 as probably an offshoot of modern man, although there is still discussion as to its exact position in human evolution. Source: http://elifesciences.org/content/4/e09560. Author Lee Roger Berger research team

cheese production, but these are on a very small scale. It is not just in the USA, Britain, Europe, and Australasia that there is documented cave damage. There seems to be a growing problem in the spectacular Asian karst with fragile caves facing growing development risks and the biodiversity living in these landscapes facing major problems (Clements et al. 2006). As tourism expands in response to a growing Asian middle class, caves are being developed as scenic attractions. There is also a thriving construction industry which needs limestone and logging and land clearance which can affect karst systems. Hence there are threats to cave biodiversity, and there is a lack of management, with a low priority for cave conservation. It is not just the fact that there is a high level of endemic species and the caves act as biodiversity reservoirs but these caves have the potential for future archaeological and palaeontological discoveries. There are many invertebrates, bats, and fishes living in these caves too. Of 143 species from karst regions of the world which are globally threatened (IUCN), 31 occur in South East Asia, and these figures are thought to be conservative. There have been many species lost and, for example, at least 18 species of karst plants in Peninsular Malaysia have become extinct.

There are several types of caves in terms of their geology and geomorphology, but a predominant number are in limestone, dolomite, and gypsum and are formed because these rock types are soluble (Fig. 12.2A). Other types of cave are formed as basalt lava tubes (Fig. 12.2B) and in glaciers by meltwater (Fig. 12.2C), but these are much less important in total number, especially the latter as they are so ephemeral because of glacier movement and meltwater stream changes.

Fig. 12.2 (A) Long Churn Cave in soluble limestone: one of the entrances with Ingleborough in the background. Photo by D. Huddart. (B) Lava tube and lake, Jameos del Agua, Lanzarote: formed by lava flow from an eruption of La Corona volcano, which then partially collapsed to give several underground access points. Photo by D. Huddart. (C) Glacier cave in Iceland. Photo by D. Huddart

12.2 How Can Caves Be Damaged?

We start by looking at how caves can be damaged, what can be done to prevent this damage, and then go on to evaluate the management techniques that are currently being used and what is our responsibility as outdoor and environmental educators to preserve the cave environment. Generally most damage is probably accidental but it is insidious, and although each incident like a straw stalactite being broken is hardly noticeable, cumulatively the result is irreparable wear and tear. Within the British Isles, for example, new cave systems are discovered only rarely and a cave destroyed is a cave destroyed forever. Some cave passageways are active streamways, with no deposits and few formations. These are robust environments where little or no damage to the cave by recreation is likely to occur but many caves are small and constricted with fragile formations and vulnerable sediments which are easily damaged. High level, inactive caves and those that are well decorated with speleothems are much more prone to damage. However, it is not practical to generalise, and each cave should be seen as unique.

A newly discovered cave system is the only true natural ecosystem available for study in a country such as Britain, but although caves provide a unique environment, they also provide a unique challenge to the conservationist. An example of this type of problem was documented by Hewitt (1992) who described the effects of a new discovery in Lathkiller Hall in 1990 in Lathkill Head, the wet weather resurgence of the river Lathkill in the Peak District (Derbyshire). It was well decorated with all kinds of flowstone decorations, and with excellent cave sediment sequences. Up to January 1991 damage was minimal, with less than eight people visiting and under 20 hours of caving time spent in the cave. Baseline observations were made, and there was a system to record the numbers visiting. In 14 months 95 people visited, there was damage to two stalagmite curtains, and there was erosion of mud in a crawl. The author realised that he was documenting at least partly his own effect on the cave and two others who were digging to extend the cave. These three cavers accounted for 34 out of the total visits, and the author realised he was significantly eroding the mud at the exit of the crawl while trying to determine the potential for change.

Caves are vulnerable to human pressure because this pressure can be so concentrated. It is also true that there has been relatively little scientific work examining the ecological effects of caving. Williams (1966) found reduced algal and bacterial populations when investigating specific sites in two well-used Welsh caves (Ogof Ffynnon Dhu and Porth yr Ogof), and threats to bat roosts have been well documented, but Sidaway (1988) suggested that the changes occurring are only apparent over long cycles which makes population trends difficult to assess. In 1972 a National Cave Association report on the state of conservation and access in caves and mines in England and Wales made one obvious conclusion: the extent of usage a cave receives reflects the extent and nature of damage occurring, but as we have already seen it can depend on the cave as each cave is unique and can present unique problems to solve. Trampling pressure can occur on the access routes to the caves and around cave entrances and exits. Inside the cave because usually cavers follow well-defined routes, trampling can cause unintentional wear and tear by cavers and their equipment. The passage floors can be eroded, especially where soft cave sediment floors are lowered, or compacted which might mean loss of habitat as the fauna cannot penetrate the compacted sediment. The cave can be made more accessible by increasing the size of the passages, for example, the crawl in Cwmdwr Quarry Cave (South Wales), and in some caves there can be erosion of the rock surfaces by ladder and rope grooves. This trampling can disturb cave biota, fungi can be scraped away, and the flora around the cave entrances/exits can be damaged. It is particularly important not to disturb roosting bats, and in Britain it is illegal to do so under the Wildlife and Countryside Act (1981).

There has been deliberate and unintentional vandalism to some caves, and Wilmut (1972) showed that even 45 years ago 13% of features in all known British caves and 27% of major caves had been damaged. All it takes is a muddy hand to destroy a white calcite formation or the accidental emplacement of grease from fingertips onto calcite to inhibit formation growth. Rather more obvious are the effects of Victorian collectors who removed flowstone formations, or Alexander Pope who had most of the stalactites shot down in one cave for his collection, or the deliberate removal of formations to make a squeeze passable. Graffiti is obvious on some cave walls, for example, the spectacular spray painting at Buckner Cave (Richard Blenz Nature Preserve, Indiana), and the building of way-marking cairns and scratched signs and arrows can be viewed as deliberate vandalism, a classic example being the route from Bar Pot to the main chamber of Gaping Gill in the Yorkshire Dales.

All kinds of rubbish can be dropped or deliberately left underground by cavers, like food waste, wrappers, items of broken equipment, cigarette ends, and rubber from decomposing clothing. Some of this enriches the food supply which can result in, for example, an increase in one springtail species around Camp One in Otter Hole (South Wales) and a loss of three other species at a popular eating/lunch stop in that cave. Spent carbide used to be a major problem and could find its way into the food chain and also leave small piles and soot on the passage walls and roof. This spent carbide eventually reacts to produce acetylene gas and lime, sulphides, and metals which may kill cave fauna, especially in low-energy cave systems. Skin cells and fine lint introduced by humans bring bacteria which is an extra source of energy for the cave biota. Tobacco smoke contains a powerful insecticide which challenges, if not kills, many invertebrates in the relatively enclosed cave. To illustrate the amount of litter that can be found in caves, the Red Rose Cave and Pothole Club removes hundreds of kilos from the Easegill system (Yorkshire Dales) during its annual clean-up weekend.

To extend cave systems or to find new ones, some cavers and caving clubs deliberately dig in caves or at potential entrances. The result can be piles of debris and worn out or abandoned equipment and some of these digs can last for tens of years as at Great Douk (Fig. 12.3).

Fig. 12.3 Great Douk dig, vertically from the collapsed cave entrance section to try and connect the active streamway from the cave to the River Greta to the west. Note the shoring, scaffolding, and ladder. Photo by D. Huddart

Passage shapes can be altered, or the character can be changed due to digging or accumulation of waste material originating from a dig. On a bigger scale, blasting, the drilling of shot holes, and the use of explosives has in the past changed the morphology of some caves. This can also lead to the subsequent temporary abandonment of a cave due to toxic fumes as in Sell Gill Holes (Yorkshire Dales) in October 1993 which may also have an effect on cave fauna. Deliberate sump drainage and other hydrological alterations in the name of exploration allow inaccessible passages to be used. Usually they fill up again fairly soon but the duck in Valley Entrance (West Kingdale, Yorkshire Dales) was lowered. As it was near the entrance, it formerly used to dissuade many leaders of novice groups from using the cave since most of the trip would have to be made subsequently in wet gear. Now this cave is subject to much greater use as the lowering of the duck allows a much drier and more comfortable trip. Enlarging of entrances during digging can lead to changes in air flow which may lead to desiccation of rock and sediment surfaces but this damage must be minor. Where cave diving is necessary for exploration, the damage caused by air-bottles carried to the first dive site can be a big problem and formation damage in constricted sumps is inevitable. The potential downsides to digging include:

- Alteration of the natural appearance of the entrance or landscape.
- Changes to the patterns of air circulation within the cave and the accompanying impacts to the ecosystem and mineral growth.
- An increase in drying, especially during the winter, due to cave microclimate disruption.
- Alteration in drainage characteristics and patterns of sediment transport within the cave due to changes around the entrance zone.
- Possible creation of an unstable passage with an increased danger of rockfall.
- Potential increase in the number of visitors to the cave.

There used to be much in-situ equipment such as bolts, pegs, permanent ladders and handlines, and sump rope, especially at pitch heads, much of it old and abandoned, but with the use of ecobolts this has considerably reduced. Dye testing resulting in the temporary coloration of the water in an effort to trace the hydrology of a cave is not really a problem but the loss and abandonment of dye detectors can be. Camping underground is relatively uncommon but where it does occur it poses much the same kind of environmental problems as on the surface: littering potential, disposal of human waste, and large amounts of gear. Occasionally deaths occur underground and in Britain at least one caver has been concreted into a squeeze where he became stuck and more bodies lie lost in sumps where they drowned.

An unusual attempt was made to document the environmental impact of caving at Pridhamsleigh in Devon by Sargent (1998) as he had noted that mud was disappearing or had totally disappeared from parts of the cave, for example, there was a 2 m trench in Bishop's Chamber. He measured the amount of mud from different types of caving suits and estimated that 0.771 kg was the average amount of mud extracted from the suits/trip, which if the estimated 9000 cavers per year was correct was a total of 6939 kg. However, different caving suits absorb different amounts of moisture and the amount of mud absorbed. The technique was based on 30 measured suits with three different types: a cotton boiler suit, a Daleswear lightweight Cordura suit, and a Warmbac heavy duty Cordura suit, and weights were measured before caving, after caving, and after drying. There was a lack of data for mud on other caving gear and on hands and faces, but after one trip it was found that the total mud that could be added to the suit figures was 0.224 kg for the belt, 0.346 kg for the helmet, 1.218 kg for the boots, 1.137 kg for the battery, and 0.187 kg for headset. This totalled 3.112 kg for the gear. This cave is very muddy but the figures of mud eroded from the cave and extracted are large, even if the figures are only best estimates and the total number of cavers is again an estimate. There could be a major loss of scientific information from some caves because of this type of erosion where there are large muddy sections or even mixing of the sediment stratigraphy as at Black Chasm Cave (California).

Light pollution in many popular caves and show caves can cause unnatural algal growth on cave walls as the atmosphere and temperature can be changed. For example, a single person releases heat equivalent to that of a light bulb, and a single party of 87 tourists raised the temperature of the cave air by 1.5 °C during a five-minute visit at White Scar Caves (Yorkshire Dales). This can affect the water vapour capacity as a 1 °C temperature rise results in an eightfold increase.

In the artificially illuminated parts of caves, the development of heterotrophic biofilms and phototrophic communities serving as primary producers is common. This community, generally known as lampenflora, is usually composed of different microbes, eukaryotic algae, cyanobacteria, bryophytes, mosses, and ferns, for example, in Reed Flute Cave, Guilin, Guangxi (China), where there is multi-coloured lighting and extensive lampenflora in the show cave and in Korean show caves (Byoung-woo 2002). The lampenflora adheres strongly to the substratum and deteriorates speleothems. Nutrients and moisture levels are often sufficient to support its growth. Rock surfaces, sediments, and artificial materials around lamps often become colonised by these phototrophs.

Biomass fixed due to light energy, together with other organic matter brought by tourists on clothing and skin, becomes available to cave organisms. The lighting system can alter the microclimate, favouring the growth of photosynthetic organisms, as happened in the Lascaux caves, France, where algal colonisation damaged the cave paintings. Lampenflora is completely dependent on light, as the light saturation point of these species is quickly reached at the cave temperature. These phototrophic communities are inappropriate from an aesthetic point of view, cause degradation of colonised substrata, and produce weak organic acids that can slowly corrode the speleothems.

Direct impacts that are particularly relevant to cave microclimate include construction of access routes through caves and entrance modifications that alter cave airflow and elevated air temperatures from the accumulated body heat from large numbers of visitors. The build-up of carbon dioxide in the cave from human breath can combine with moisture to corrode speleothems and bedrock. Dust accumulation in the cave can also be a problem. Cave dust is composed of lint from clothes, hair, and flakes of dry skin that provide additional food sources for carbon dioxide-producing bacteria and from microbial activity in general. Similarly, abandoned wooden walkways and railings provide food sources for micro-organisms, resulting in decomposition and increased carbon dioxide emissions into the cave air (Russell and MacLean 2008). Cave lighting may heat up and dry the ambient air, inhibiting speleothem growth. Although broad spectrum emission lighting commonly leads to the growth of lampenflora (algae and mosses) on clastic sediments, speleothems, and cave walls, narrow spectrum and relatively cool LED lights reduce lampenflora growth and heat output. Many of these impacts are cumulative and often lead to irreversible degradation to the cave ecosystem.

Sources of carbon dioxide in show caves, such as the Waitomo Glowworm Cave in Tasmania are:

1. respiration of people in the cave
2. outgassing from water flowing through the cave and from vadose waters
3. oxidation of organic material and respiration by micro-organisms
4. diffusion of soil gas through soil and rock into the cave.

In the absence of air exchange with the outside environment, the concentration of CO_2 in the cave air is a function solely of the rate of CO_2 input from sources 1 to 4 above.

Sinks of carbon dioxide in caves are:

1. airflow and air exchange with the outside (ventilation)
2. solution in undersaturated cave water
3. diffusion through (porous) cave walls.

CO_2 concentration in the cave air is normally greater than that outside, so ventilation is the major control on the concentration of CO_2 in cave air. In show caves, humans are clearly the major cause of elevated concentrations of CO_2, directly through respiration and, to a lesser extent, indirectly by promoting the activity of bacteria and other micro-organisms that feed on organic matter, including skin and hair shed from the human body. People exhale air that is slightly depleted in oxygen and enriched in CO_2 (approximately 4% CO_2). Concentrations depend on visitor numbers and ventilation rates through the cave. A single person exhales CO_2 at approximately 17 l hr^{-1}, and thus a tour group of 200 visitors expels about 3360 l hr^{-1}. Concentrations of carbon dioxide of up to 5000 ppm have been recorded in the Waitomo Glowworm Cave, but the allowable level that should be specified in cave management guidelines is open to debate (Cigni and Burri 2000; Dragovitch and Grose 1990). Added to this is the concern that when carbon dioxide concentrations exceed about 2400 ppm in the Waitomo caves, water can combine with CO_2, forming a weak acid, which can lead to corrosion of limestone features of the cave.

As Gillieson (1996) estimated the number of visitors globally to show caves at the end of the twentieth century at over 20 million and Aley (1976) suggested at least 5 million/yr visit show caves in the USA alone, the light pollution problems outlined above are important and have been discussed by Dragovitch and Grose (1990), Russell and McLean (2008), de Freitas (2010), and D'Agostino et al. (2015).

External impacts to cave sites include all the usual problems associated with the use of an outdoor recreation site such as parking area problems; litter; congestion; damage to flora, walls, and fences; and footpath erosion and damage to walls and fences resulting from the access routes to caves. There is also the dumping of waste into caves by farmers.

Most threats to caves can be attributed to unintentional damage and general wear and tear by cavers. To reduce this threat, leaders of groups should encourage the careful movement of individuals and their equipment underground. Much of the threat which remains is specialised in nature and to reduce it requires debate and decision-making by individuals with a similarly specialist knowledge, and usually this will be by those who are the cause of the threat originally. As Britton (1975) suggested though "only unpopular actions are effective in preserving caves and unpopular actions succeed only when the prevailing climate of opinion renders them acceptable."

12.3 Cave Fauna and Flora

Cave fauna is often highly specialised, adapted to live in such an environment and often endemic and very rare and includes snails, spiders, beetles, shrimps, pseudoscorpions, and cave fish (examples in Fig. 12.4A, B).

Fig. 12.4 (A) Blind albino crab (*Munidopsis polymorpha*), Jameos del Agua lake, Malpais de la Corona, Lanzarote. Photo by D. Huddart. (B) *Zospeum tholussum*, a microscopic cave snail completely blind with a translucent shell, from the Lukina Jama-Trojama cave system (Velebit Mountains, Croatia). Ospeum species (Gastropoda, Ellobiidea, Carychiides) from 980 m depth in the Lukina Jama-Trojama cave system (Velebit Mtns, Croatia) [*Subterranean Biology*, 45–53. Authors: J. Bedekand and Alexander M. Weigand]. Photo by J. Bedek. (C) Devil's Hole (*Cyprinodon diabolis*). Source: National Digital Library of the United States Fish and Wildlife Service. Photo by Olin Feuerbacher (USFWS)

Examples include the Bone Cave harvestman in Travis and Williamson Counties (Texas) which was added to the United States Fish and Wildlife Service (USFWS) Endangered Species list in 1988, along with others such as the Kretschmarr Cave mold beetle and the Tooth Cave pseudo-scorpion. Warton's cave spider in 1992 was described from a single individual in Pichule Pit, a shallow cave, in Travis County and was last seen in 2000. There have been lawsuits from the landowner, who gated the cave with a lock which is now rusted shut, and this has been a test case for conservation against the rights of landowners. Another example is the blind cave beetle (*Leptodirus hochenwartii*) has been found in a cave in the Inner Carniola region, Slovenia, but the exact location has not been given because of conservation concerns. The Devil's Hole Pupfish exists with a population of under 200 individuals in a single groundwater pool in a Nevada cavern (Fig. 12.4C).

This fauna plays an essential role in underground ecosystems by decomposing organic matter and recycling nutrients through the food web. Many of them are very rare and include ancient, primitive forms no longer found on the surface. They provide important information for studies of evolution and ecology. However, although cave animals are adapted to living underground, it is vital we recognise that their ecosystem is linked to the surface above and any changes we make here can affect their subterranean habitat. Many cave creatures live in the water and feed on debris washed into the cave. Others feed on creatures that live in the water. For example, the glow-worm builds its silken nest above streams and uses its light to attract caddisflies and other insects (caddisflies have an aquatic larval stage). For all these creatures, maintaining an unpolluted water supply is vital.

Cave environments are strongly buffered against the daily, seasonal, and longer-term surface climatic changes. They provide stable, sheltered, and moist refuges for animals which might otherwise not survive on the surface. Green plants cannot grow in the complete darkness of caves, so the food supply for cave creatures must ultimately come from the surface. Plant material falls or is carried in by streams, while animals wander into caves, fall, or become swept underground.

Hence, cave ecosystems directly depend upon the surrounding surface environment. This means it is essential that we maintain the natural soil, vegetation, and water quality around caves. The special nature of karst makes it particularly vulnerable to degradation and such areas should be treated with special care.

12.3.1 Zones in Caves

The cave environment can be divided into four distinct zones:

- *Entrance zone*: here the surface and underground environments meet.
- *Twilight zone*: here light progressively diminishes to zero. Plants such as ferns, mosses, liverworts and algae cannot grow beyond the limit of light penetration.
- *Transition zone*: light is absent here although surface environmental fluctuations such as temperature and moisture are still felt. Cave crickets often congregate here, and on suitable nights venture outside the cave to forage for food.
- *Deep zone*: remote from entrances, the deep zone is completely dark. Here the relative humidity is high and evaporation rate is low. Temperature is nearly constant all year around.

Creatures living in this latter zone have become adapted for life in the dark, no longer needing vision. They are called troglobites, they may have reduced body pigment and eyes and longer legs and antennae to help them find food in the darkness. Only small amounts of food ever reach the deep zone so troglobites have to survive long periods without food.

There is also a long list of specialised marine cave species, many again extremely rare and endemic to a single cave or area. The world register of marine cave species can be located at www.marinespecies.org/docs/activities/2015/WORCS_report.pdf. This is now an opportune place to briefly discuss the possible cave diving effects and suggest that preventing cave damage is every cave diver's responsibility. Whether diving in marine or terrestrial caves, divers should try not to disturb silt, they should avoid pull-and-glide propulsion where they grasp the rock and pull themselves forward to advance movement because this can cause cave damage, especially in low-flow caves. Ceiling push-off should be avoided due to potential damage by feet, and they have to be careful with back-mounted tanks to avoid damage.

12.3.2 Bats in Caves

The largest aggregates of living vertebrates are found in caves (bats), and in the 1960s the mid-summer colonies of adult Mexican free-tailed bats (*Tadarida brasiliensis*) in 17 caves in SW USA were estimated at 150 million individuals. However, the survival of many bat species depends on natural caves. For example, of 39 bat species in temperate America, 18 rely substantially on caves, including 13 species that dwell in them all year whilst the remaining 5 depend on caves for hibernation sites. The figure in China is much greater as 77% of the known bat fauna (101 out of 131 species) roosts in caves there (Luo et al. 2013). The bats provide many benefits for ecology outlined by Furey and Racey (2015) and Medellin et al. (2017), including the guano as a source of food for many invertebrates.

Recreation users of caves can disturb both hibernating and nursing bat colonies, and disturbance is likely to be more severe if there is a large party in a system occupied by bats. Thomas (1997) showed that non-tactile disturbance from seemingly innocent cave visits during hibernation periods can cause bats to arouse and maintain significantly greater flight activity for up to eight hours afterwards. Such arousals are highly detrimental to their overwinter survival, and non-tactile disturbance during other critical periods such as reproduction may lead to: (1) death of young that lose their roost-hold and fall to the cave floor, (2) females abandoning the roost for less ideal sites where prospects for reproductive success may be reduced, (3) greater energy expenditure among females and less efficient energy transfer to young (translating into slower growth of young and increased foraging demands on females), and (4) reductions in the thermoregulatory benefits of a roost as a result of decreased numbers of bats frequenting the site.

Bats have a fat reserve which they use during hibernation and if a bat is awoken from hibernation then the fat reserve is consumed far faster than that consumed during hibernation. Responses to tactile stimulation showed a significant increase in energy expenditure when handled (Speakman et al. 1991) which shows that disturbance can also be caused by conservationists monitoring bat populations and in some circumstances may be of more significance than the more general disturbance exerted by cavers or tourists. Speakman et al. (1991) predicted that each non-tactile disturbance decreased fat stores by 0.01 g whilst each tactile disturbance decreased the stores by 0.05 g.

As a result, uncontrolled human disturbance often leads to decreases in numbers of bats roosting in caves and mines (Tuttle 1977). For instance, disturbance in caves in West Virginia, USA, occupied by the Indiana myotis (*Myotis sodalis*) and Townsend's big bat (*Corynorhinus townsendii*) resulted in a decline from 1137 bats to 286 in one cave and from 560 to 168 in another (Stihler and Hall 1993).

The increase in cave tourism has caused problems, especially in South East Asia, and the commercialisation of Fourth Chute Cave in Quebec resulted in the abandonment of the largest hibernacula of the eastern small-footed Myotis known at the time in Eastern North America (Mohr 1972).

The biggest problem facing bat populations in North America since 2006 has been the accelerated loss of bats due to the white nose syndrome (WNS) (Fig. 12.5A for a healthy bat and Fig. 12.5B for an affected bat).

Populations in some caves have dropped by 90–100% caused by the spread of the fungus *Pseudogymnoascus destructans*. It has killed over 6 million hibernating bats in North America since the winter of 2006–2007 when it was detected on a bat in a cave near Albany (New York). It has spread to 29 states as well as 5 Canadian prov-

Fig. 12.5 (A) Healthy little brown bats, Aeolus Cave or Dorset Bat Cave in the Taconic Mountains in East Dorset, Vermont. Before white nose syndrome reduced the bat population, it was known as the largest bat hibernaculum in the north-east USA. Source: US Fish and Wildlife Service Headquarters. Photo by Dolovis. (B) Bat roosting in cave with white nose syndrome, Greeley Mine. Vermont. Source: National Digital Library of the United States Fish and Wildlife Service. Photo by Marvin Moriarty/USFWS

inces and is spread from bat to bat, although it is partly spread by cavers. The USFWS recommend anyone in caves follow the agency's white-nose decontamination protocol. This elaborate procedure involves the washing of bodies, clothing, vehicles, and equipment, and there is restricted access to caves where detected.

12.4 Management Strategies to Conserve Caves

12.4.1 Potential Strategies

There are many potential management strategies, and each one depends on the individual cave concerned, and each cave should have one or find one of its own. More popular caves will need a more in-depth strategy than caves that are rarely used. However, whatever the status of the cave, it has to be appreciated that once damage has been done there usually can be no rectification in our lifetime as caves have developed over thousands of years and sometimes much longer. However an example of the removal of graffiti from Buckner Cave in Indiana on the Richard Blenz Nature Preserve which was donated to the NSS which was heavily graffitied by spray painting can be seen where sandblasting removed the worst damage.

As Aley (1976) suggested "The carrying capacity of a cave is zero," and because most damage and environmental change are irreversible, there needs to be determined the environmental management techniques that are appropriate for a given cave. The cave manager should be concerned with defining the desired, or optimal level, or range of environmental conditions that should occur and then maintain them in that cave. The cave system is the only true natural ecosystem available for study in a country such as the UK but only lasts a very short time period after the cave discovery. Caves provide a unique environment but also a unique challenge to the conservationist. They are vulnerable yet are also subjected to concentrated human pressure. However, throughout the world there are various organisations responsible for cave management. For example, in the USA the Bureau of Land Management (BLM) manages nearly 800 caves in the 11 western states, whilst the National Park Service (NPS) manages caves and karst scenery in 120 parks (81 contain caves and over 3900 caves are known throughout the park system). The United States Forest Service (USFS), under the Department of Agriculture (DOA), manages 193 million acres in the form of 155 National Forests and 20 National Grasslands. The mission of the United States Department of Agriculture Forest Service is to sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations. National Forests provide sustainable forest products, mining leases, and recreation opportunities, including in caves across the country. Good examples of cave and karst management can be taken from the Arizona National Forests where the following cave and karst management guides have been published for Kaibab National Forest (2014), Apache-Sitgreaves National Forest (2014), Coconino National Forest (2014), Tonto National Forest (2014), and Coronado National Forest (2012). Along with items such as cave classification, monitoring, and inventory procedures, there are caving ethics for both Forest personnel and the general public. There is also a general Arizona National Forest Cave and Karst Management plan (Keeler and Bohman 2013) which illustrates clear and acceptable guidelines and policies that can be implemented in a uniform way. Karst and Cave Areas are designated as a separate land use designation in the Forest Plan, and the latter can be updated without having to go through the extremely long Forest Plan amendment process. The Plan draws from and highlights the relevant sections of federal laws and statutes, including the United States Code (USC), the Code of Federal Regulations (CFR), and Forest Service manuals (FSM, US Forest Service 2009). The USFWS manages approximately 96.4 million acres of land in the form of roughly 545 national wildlife refuges and approximately another 90 districts and areas. The National Wildlife Refuge System Administration Act of 1966 identified lands under which the USFWS was to manage for the protection of wildlife and wildlife habitat. Their mission is working with others to conserve, protect, and enhance fish, wildlife, and plants and their habitats for the continuing benefit of the American people. The NPS manages approximately 84.6 million acres in the form of 391 units, 58 of which have national park designation. Over 4000 caves have been identified from 85 NPS units. The NPS mission is: "to promote and regulate the use of the national parks…which purpose is to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." NPS policy also states that all caves within their management are significant and thus will be managed to their fullest protection. Nolfi (2011) illustrates that this always has not always been the situation with a case study approach from the Great Smoky Mountains National Park, Harley et al. (2011) established a cave inventory for West Central Florida caves to stimulate the development of management strategies, whilst Donato et al. (2014) described a conservation status index for the management of cave environments.

At 66 million acres the Bureau of Indian Affairs (BIA) manages a substantial amount of land, but not all the land is managed for public use and within the lands, management varies significantly based on resources and needs. Although cave protection is provided through several acts of congress, the Federal Cave Resources Protection Act (FCRPA) does not apply to BIA lands and thus provides no protection to caves they manage. It is important to note that additional tracts of federal land are managed by agencies that do not fall under the jurisdiction of the Department of the Interior (DOI) or DOA and therefore are not bound by FCRPA. That does not imply that cave resources are not considered in land management. For example, the Department of Defense (DoD) manages over 25 million acres and the Department of Energy 2.4 million acres. Significant cave resources fall under management of each of these agencies. The DoD's Legacy Program has assisted in the identification of 18 new cave species from 2 Army bases in Texas. Close to 1 million dollars was spent over 12 years to find and research caves and cave fauna at those two bases (Elliott 2005). Tennessee Valley Authority manages over 293,000 acres and has known cave resources. When the FCRPA does not apply, cave protection is often afforded under the Endangered Species Act, 1973.

12.4.2 Federal Cave Management and the National Park Service

With the development of the FCRPA, its federal land management agencies under both the DOI and the DOA are required to inventory and list significant caves on federal lands and to provide management and dissemination of information about caves. In 1998 Congress passed the National Cave and Karst Research Institute Act of 1998 in order to further promote cave and karst research. In addition to these broad federal regulations regarding cave and karst management, the NPS is also guided by more specific legislation, such as the Lechuguilla Cave Protection Act of 1993 which protects land above and around the cave. In order to fulfil these obligations, federal land management agencies are continually devoting increased resources to karst management, as concepts and practices in cave and karst management continue to evolve. The NPS' cave management falls under the advisory of the Cave and Karst Program. One-hundred and twenty park lands have identified cave and karst features, with 85 containing caves. Under the FCRPA and CFR Title 43—Public Lands: Interior, Part 37 - Cave Management, the NPS designates all caves as significant caves and manages accordingly. NPS resource managers are guided in managing, protecting, and conserving all natural resources in their unit by the NPS' Director's Orders guidance; Natural Resources Management Reference Manual (RM#77). The guidelines under RM#77 specify the policy and programme directives, the authoritative legislation, methods of protection and fulfilment of legislation, as well as an explanation of the roles and responsibilities of those who are in position to manage caves and karst. Within the NPS' RM#77, the Cave and Karst Management section provides guidelines for the management of caves, encompassing the many disciplines necessary to protect and perpetuate natural cave systems. Guidance is oriented towards the needs of anthropogenic challenges within caves ranging from resource planning for karst protection to direct management of developed caves (as in "cave parks," such as Mammoth Cave or Carlsbad Caverns National Park). It is stated that parks with small, undeveloped caves should adapt and apply relevant management as they see fit for their conditions. Management of caves includes protection of soils, surface landforms, natural drainage patterns and hydrologic systems, and cave microclimate and ecosystems (RM#77). Although NPS units with cave resources are mandated by RM#77 to develop and implement a cave management plan, many currently do not employ cave management plans.

However, several NPS units employ cave and/or karst specific management plans for optimal management. Several of these provide developers of management plans with an understanding of the concerns and the needs to make plans effective and efficient. Plans from Carlsbad Caverns NP (2006), Grand Canyon NP (GRCA) (2007), Sequoia and Kings Canyon NP (1998), Timpanogos Cave NM (TICA) (1993), Cumberland Gap NHP (1998), Wind Cave NP (2007), and Jewel Cave NM (2007) are good sources of information applicable to most managers in developing specific cave and/or karst specific plans.

12.4.3 NPS Cooperative Relationships

The NPS has a memorandum of understanding (MOU) with the NSS for the purpose of support and encouragement of the NSS' involvement in the inventory, scientific study, management, planning, and protection of cave resources on agency-administered lands. In accordance with this MOU, the NPS will provide access to caves under their management, advise opportunities for cave-related studies and projects, advise of NPS research and cave management policy, assist to develop and implement safety programmes and search and rescue plans for the cave- and karst-related projects/studies, and acknowledge the work products and data gathered by the NSS. There is also a specific MOU with the Cave Research Foundation (CRF) to facilitate project development where they are the primary collaborator for in-cave scientific research. The American Cave Conservation Association has an MOU with the NPS to foster stewardship relationships with commercial cave interests in national parks. They also have worked to define guidelines and assistance for cave gating projects. In addition, Bat Conservation International (BCI) works within an MOU with the NPS to provide guidance, support, and protection of bats in the USA. These MOUs, as well as others, all foster protection to cave- and karst-related resources within the NPS.

As mentioned earlier, there is also an Interagency Agreement for the Collaboration in Cave and Karst Resources Management between the NPS, USFWS, BLM, United States Geological Survey, and USFS which addresses a need for collaboration to achieve efficient management. The purpose is to achieve a more effective and efficient management of caves through their cooperation in understanding mutual concerns and avenues for better management. This need for cooperation fulfils the FCRPA and the National Cave and Karst Research Institute (NCKRI) requirements for exchange of information and cooperation.

Then there are various privately owned caves, especially show caves, and in the USA the National Caves Association was founded in 1965 by a small group of over 80 show cave owners. In the USA the National Cave and Karst Management Symposium has been an important forum for promoting, advancing, and sharing concepts of effective management of cave and karst resources for over 30 years.

12.4.4 Canadian National Parks

At least 12 of 41 national parks in Canada have caves. A group of six parks in western Canada are adopting cave management guidelines using a three-tier classification system to manage access (Horne 2005). Class 1 caves are access by application: highest resource value, not for recreation, each visit must add knowledge, or give net benefit to the cave.

Class 2 caves are access by permit where recreation use is allowed, there are some management concerns and education/orientation is possible during permit process. Class 3 caves have unrestricted public access with few or no management concerns and no permit is required.

In order to determine which class each known cave is in, three sets of factors are considered: (a) cave resources, (b) surface resources, and (c) accident and rescue potential. Cave exploration in the western Canadian mountain national parks only began in the 1960s, and this current access policy has been influenced by the remote rugged nature of the landscape and the need to work with speleological groups to explore and document park features. A change in park staff awareness of the resource has contributed greater exchange of information and opportunities for cavers to gain access and the park to know more about its resources.

12.4.5 Access Agreements and Physical Barriers

The most obvious way of controlling damage is controlling the access to caves and/or imposing a physical barrier to the entrances. For example, in the UK, access agreements negotiated by the Council for Northern Caving Clubs (CNCC) are given on their website, and examples are given below to illustrate some of the restrictions. For Birks Fell, Redmire Farm, Buckden, near Skipton, the agreement is with Messrs. Dacre Son and Hartley, for, and on behalf of, W.A.G. Watson:

- Access to the cave is by track from Redmire Farm only.
- Agreed access is through Birks Fell Cave entrance only unless written consent is obtained from the agent and tenant of Redmire Farm.
- No cars to be taken to Redmire Farm. Buckden car park to be used.
- All gates on the access track must be closed.
- No camping permitted.
- Access to be granted to member clubs, one per day.
- No access from 1 November to 15 April the following year.
- CNCC to be responsible for making good any damage resulting from the access to the cave and any claim arising from the damage.
- CNCC will indemnify Mr. Watson, his agents, and tenants against any claims for accidents or damage. All persons will visit the cave at their own risk.
- Agents and tenant Mr. Horner to be notified monthly in advance of all bookings.
- Member clubs must call at Redmire Farm, when going to and when returning from the cave, but, the tenant does not accept responsibility for notifying the authorities in an emergency.

- The tenant may deny access on any day by giving reasonable notice.
- The owner retains the right to terminate the agreement at any time by giving written notice.

For Casterton Fell the access agreement is administered on behalf of the Whelprigg Estate by the CNCC. Club access is only for CNCC and British Caving Association (BCA) member clubs. It is a condition of the access agreement with the Whelprigg Estate that novice cavers are not permitted into the Easegill system and that the system is not used for training cavers in caving techniques (other than the techniques used by experienced cavers, for example, photography, surveying, and conservation).

- Five permits per day at weekends and two permits per day on weekdays with a maximum of eight cavers per permit and a maximum of two cars per permit.
- Written application on club letter headed paper (with stamped addressed envelope) or via email if you have applied in the past.
- Subject to availability, permits can be issued at short notice, however the fell is often booked up several weeks in advance so as much notice as possible is best.
- CNCC must provide a list of authorised clubs. Access to all the caves must be on the agreed routes; these routes are displayed on the reverse of the permit.
- Cavers must abide by the countryside code and the cave conservation code. Particular attending must be applied during the breeding and nesting season for birds and also at lambing time.
- Breaches of the access conditions can result in the withdrawal of future permits and can in certain circumstance cause the Fell to be closed.
- No digging or explosives are allowed on the Whelprigg Estate's land.

12.4.6 Secret Conservation

This is where a cave discovery is not publicised so few cavers visit. It is frequently adopted at the start of a find but it is only suitable in the short term as it is elitist, divisive, controversial, and often counter-productive as a conservation technique. We have seen from an earlier example information related to cave discoveries spreads quickly so secret conservation does not work.

12.4.7 Zero Access

The most radical and revolutionary form of conservation is to have zero access to a cave and the thinking behind this is simple: people damage caves, caves are delicate environments susceptible to damage, and therefore no people, no damage. However, this raises many arguments regarding the educational, censorship, and freedom of movement aspects and has moral issues too but it cannot be neglected as a conservation tool. In Britain an example of this approach are the Stump Cross Caverns which is really a show cave, but this does not cover the whole cave and there are other sections which could be explored. The book *Northern Caving* suggests that permission to enter these sections of the cave is unlikely to be given but it is possible to write to the show cave to try and gain access.

12.4.8 Restricted Access

This management tool only allows certain groups to enter the cave system, for example, educational groups, research groups, exploration groups, caving club groups affiliated to a national park committee and general public groups in show caves. There is a set system of entry organised. An example would be the leader system in the Mendips for St. Cuthberts, Shatter, Withyhill, and Reservoir caves where parties are limited to not more than five people as greater numbers are believed to increase carelessness and damage. However, Stanton (1982) suggests that in this system "they demand a good deal of determination and dedication on the part of the leaders, deterioration still occurs but at a much slower rate." Some caves require a recognised leader for the trip as in Dan yr Ogof (South Wales) where the leader is generally someone from the South Wales Caving Club who has visited the cave at least three times and has proven that they are aware of conservation and safety issues. Again groups are generally limited to five people so that each person can talk to each other without having to overtake another person and risk straying from the path and disturbing formations. It may be looked upon as elitist, and if combined with gating then it could be visually offensive to the natural environment.

12.4.9 Periodical Access

This refers to where certain groups have access only at a certain time of year, in other words a caving season. This would intensify the use over a single time period and the idea is that the cave could recover over the closed season. However there is no real evidence that this is the case. In the Yorkshire Dales, this closed season is different for different systems, for example on Leck Fell and the Pipperkin-Nipperkin system, it is between 1 April and 30 June whilst in the Mongo Gill-Shockle Shaft, it is during May and July. The major difficulty here though is the enforcement of access.

12.4.10 Booking

This can be best achieved through a management strategy, but this lack of spontaneity and rigidity by having to book to take part in one's chosen pastime can put people off either taking part or booking. Again the Leck Fell system requires written application to the CNCC one month in advance, and the problem is again how to enforce this system. In the USA, for example, the Great Basin National Park in Nevada has over 40 caves, and to cave there has to be an application for a cave permit at least 2 weeks before the trip. They are approved for those who can demonstrate experience with both horizontal and vertical techniques, cave conservation ethics, and expertise with the required equipment and can certify that their equipment is clean and disinfected. This permit must be in possession whilst caving, and the group is limited to between three and six people.

12.4.11 Gating

This creates a barrier to the cave user. The most common form is a padlocked gate to the system where the caver first must obtain the key before descending (Fig. 12.6A, B). This form of restriction is effective as the caver must belong to a recognised caving club and it is thought that such club members have a greater respect for the cave in question and use it with greater sensitivity, but it does not always work as damage is still caused by club cavers. It is not always practical either as some caves have too many entrances like Porth yr Ogof. An example is Craig y Ciliau, National Nature Reserve, Agen Allwedd, where permission to use the cave must first be received from the Agen Allwedd Cave Management Committee. This involves applying and booking at least two weeks in advance of the proposed trip and involves such information as the name of the caving club or organisation, the leader's name, the number in the group, the date of the proposed visit, a deposit, and a stamped addressed envelope. On receipt of this information, a decision will be made to allow access, and if access is allowed a key is sent to the leader. This only applied to a "normal" caving trip, and extra permission is required for underground camping, surveying, exploration, or diving. Permission may be refused for any reason which the permit secretary considers is valid.

Occasionally gating might be considered actually in the cave, for example, in the White River Series in Peak Cavern (Peak District) where the discovery team (13 May 1991) felt that the formations were too delicate. This they felt justified and the gating was established from a conservation viewpoint, but they also considered that they had worked very hard in opening up the system and they deserved the satisfaction of completing the survey (Hewitt 1992). This is an example of selective access which stopped not just inexperienced but experienced cavers too, although it did not last long.

Fig. 12.6 (A) Gating at Agen Allwedd, Llangattock, South Wales. Photo by D. Huddart. (B) Bat Gate at the entrance of Skeleton Cave, near Bend, Deschutes County, Oregon; lava tube on the northern flank of Newberry volcano. Photo by United States Forest Service

12.4.12 Sacrificial Caves

In Britain the BCA encourages novice groups to avoid sensitive caves and focus activities on those caves that are capable of sustaining the pressure. This is a honeypot management approach and that by agreeing on specific caves as sacrificial where conservation interests are no longer the prime consideration, it will reduce pressure on other caves. The best examples in the Yorkshire Dales are the Long Churn system or Great Douk and in South Wales, the Porth yr Ogof system, where a car park was built to encourage use (Fig. 12.7A–C). These caves must have a high educational value, and there have to be examples of the need for conservation, otherwise the danger is that too low a priority is placed on the education in the activity and a new generation of cavers may be created oblivious to the need for conservation.

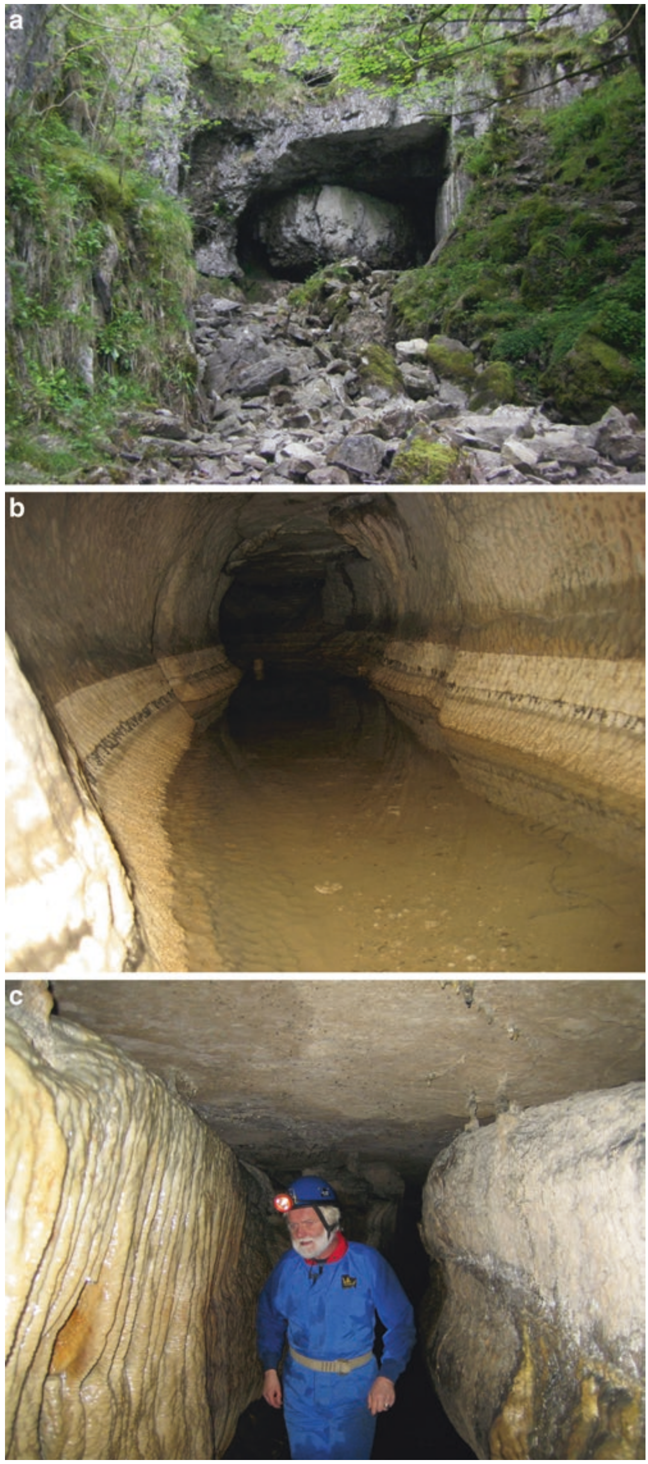

Fig. 12.7 (A) Great Douk Cave entrance and Great Douk Pot (collapse section of the cave). Entrance on ledge to the right of the photo or up the waterfall in the middle. The cave dig illustrated in Fig. 12.3 is up against the left wall of the collapsed section. Photo by Tim Stott. (B) Long Churn passage (Yorkshire Dales), active streamway, phreatic upper passage with vadose trench incised showing several water levels. Sacrificial cave used by many centres and schools. Photo by D. Huddart. (C) Great Douk sacrificial cave. The author in the upper part of the cave, note the flat bedding plane, the vadose trench, and the flowstone curtains on the left hand wall. Photo by Tim Stott

12.4.13 Endurance Conservation

Endurance conservation is where the caving is hard, awkward, and tight or the inner parts of the cave are at a distance from the entrance and therefore experience fewer cavers. There can be natural barriers to cavers that can protect passages such as sumps, ducks, canals, climbs, bolt routes, and big pitches, such as Titan, in Peak Cavern (Peak District). However, damage can still occur and examples quoted in the Cave Conservation Handbook (from National Caving Association—NCA) reinforce the view that “competent cavers are not necessarily good conservationists” and that education is an essential requirement for any long-term strategy.

12.4.14 Artificial Obstacles

Where there are vertical pitches, each party should have to place and retrieve their own bolts so that it will reduce access to those groups with the correct gear. It may be possible to create artificial sumps or block popular routes through popular caves leaving only the harder routes so as to discourage the numbers. For example, it had been suggested that in the Swildon’s Hole, (Mendips) there should be the creation of an artificial sump at the bottom of this cave which would conserve formations in Barnes’ Loop where there had been considerable damage, but this seems too late for this cave once damage has occurred.

12.4.15 Zoning Off

The process of zoning off certain sections or formations (spot taping) in order to make clear to all cavers not to proceed beyond a certain point has been tried, but plastic tape can move on uneven cave floors and not all cavers will follow the tape (Fig. 12.8). However, tape can mark a path to be followed, or cavers can walk as close to the tape as possible or on the far side of any undisturbed sediments or formations. Raised taping about 20 cm above the floor is maybe a better system to highlight the areas to be avoided. Route finding is often used as a justification for taping, but it does not do anything for conservation and should be unnecessary with good education. Taping is impractical too for some of the bigger and well-decorated caves. A solid version is where a boulder wall is erected to mark a formation, sometimes with the addition of tape. However, although

Fig. 12.8 Zoning off of stalagmites, Matienzo Caves, Spain. With kind permission from Matienzo Caves Project

successful in places as in Midwinter Chambers in Ogof Draenen (South Wales), it is again not a natural system to be recommended.

12.4.16 Formation Repair Work

It may be possible to rebuild broken formations using resin for small areas or pins for bigger repairs, but usually the pieces cannot be located and repair is generally not a realistic proposition. However, this has been attempted reasonably successfully at Matienzo Caves in central Spain (matienzocaves.org.uk/miscpics/conserve/intro.htm) and at many caves in the USA as at Carlsbad Caverns (New Mexico), Oregon Caves National Monument, and Kartchner Caverns (Arizona), and detailed methodology can be found in Hildreth-Werker and Werker (2006).

12.4.17 Exploration Policy

The potential benefits of any dig should be weighed against the disadvantages; the dig should be organised by cavers, either under the auspices of the appropriate Regional Council in Britain or through a caving club which has access agreements. In the case of open-access caves, a liaison group of interested parties should be established. Where digs occur care should be taken to minimise any damage done, and excavation should be kept to the absolute minimum. Speleothems and any cave sediments of archaeological value should be left undisturbed, but if disturbance is unavoidable, everything must be recorded and made available for research. Sections cut in sediments should be sampled, recorded, and made available for research, but of course the big problem here is that often the explorer does not have the experience or skills to record accurately the cave deposits. Dig care should adopt a common-sense attitude such as building a wall for protection from blasting so reducing potential damage from flying debris, hiding debris in dead-end passages, although creating a path with the debris produced is controversial as it gives the cave an unnatural appearance. The CNCC issues digging guidelines for sites of scientific interest which involve initially obtaining the landowner's permission. Then the landowner must submit a "Notification to Undertake Works" form to Natural England whose Conservation Adviser will make a site visit and a consent form will be issued for a specific time. There are also guidelines for digging published for cavers and resource managers by Jones et al. (2005) and an online journal and website Cave-diggers.com edited by Passerby (2002) up to the present.

12.4.18 Cave Adoption Schemes

Where clubs and cavers take responsibility for a particular cave, monitor its condition and undertake regular clean-ups. For example, the Red Rose Caving Club and the Easegill area (Pennines) and the Buttered Badger Potholing Club were cleaning up Oxlow Caverns East Chamber and North Rift in Giant's Hole (Peak District) with the latter club collecting 11 bags of rubbish in two trips. In the USA there have been many cave clean-up schemes, such as the graffiti clean-up at Bloomington Cave just outside St. George (Utah) when 48 volunteers took part over 7 weekends in 2005, which involved over 1000 hours of volunteer time. Not only did the cavers contribute time but they contributed over 90% of the project's total cost. The sandblasting technique used was discussed by Jasper and Voyles (2005), but great care must be taken as damage can occur to the rock, formations, and cultural artefacts, and some of the chemicals used in graffiti removal can be dangerous to the users. There was a case in South West France in 1992 at Maynieries Cave, near Braniavel (Tarn et Garonne) where prehistoric cave art (15,000 years old bison) was partially cleaned off the walls with steel brushes by 70 scouts before it was realised what they were doing.

12.4.19 Cave Fauna Management

The first priority in developing a strategy to manage cave fauna is to monitor the fauna by surveying to identify rare and sensitive species and

Fig. 12.9 Waitomo Glowworm Caves, New Zealand. Glowworms require careful cave management along with other specialised fauna. Photo by Shaun Jeffers with kind permission from Waitomo Glowworm Caves

habitats. This can result in the development of management options for the fauna's protection especially in relation to visitor use. Sometimes this visitor use is very high and, for example, the Waitomo Glowworm Cave is the most visited cave in Australia (Fig. 12.9), with the average visitor use just below half a million/year, with a daily average of 2296 at its peak in the 1990s.

A research programme was developed to monitor the impacts of cave users on the fauna in Ida Bay, Tasmania (Eberhard 1999), including glow-worms, cave crickets, spiders and beetles which gives baseline data for monitoring comparisons. It was noted that there were over 100 invertebrate species, with some endemic like the very rare and highly adapted blind cave beetle (*Goedetrechus mendumae*) and the glow-worm colonies are the best developed in Australia and are amongst the best in the world. This work developed from the detailed pioneering survey by Clarke (1997). Here a number of Tasmanian cave species have ancient lineages and are considered Gondwana or Pangean relicts. He documented 643 invertebrate species in Tasmanian caves and 159 of these were considered possibly rare or rare, 6 were rare or vulnerable and three were endangered. Two species had not been reported since 1910 and are considered likely to be extinct. Sixty four of the species were considered to be rare or threatened. Although trampling by visitors occurs and there has been collection for scientific research, the managers walk a difficult line between enforcement of conservation ideals and their need to maintain public access (Fig. 12.10).

Many of the threats were outside the caves associated with land-use changes and the effects of forest practice. In the Tasmanian Wilderness World Heritage Area at Ida Bay, Eberhard (1999) suggested that education of cave users was critical to the fauna's protection. Specific Minimal Impact Caving guidelines to protect the fauna were developed and promoted and the vulnerability to visitor impacts of habitat types was assessed. This included illustrated factsheets on cave fauna and Minimum Impact techniques which were made available at the Parks and Wildlife Service shop fronts and distributed to cave users from regional offices and cave sites, from cave permit applications as well as the Parks and Wildlife Service website.

There was an article on Tasmanian cave fauna and Minimum Impact caving published in the Australian Caver journal (Eberhard 1998) and public lectures were given to the local caving club, scientists, cave mangers and cave guides. The restoration of sites was carried out such as the breaking up of compacted sediment floors and the restoration of cave climatic conditions for glow-worm colonies as in Waitomo (de Freitas and Pugsley 1997). Seven Faunal Sanctuaries have been created, such as Keller's Squeeze and the Ball Room stream passage in Exit Cave for a blind cave beetle habitat. These are sites worthy of special protection because of their vulnerability because they have conservation value as examples of optimum representative, or rare habitats and/or animal communities, or because of their value for public interpretation. These

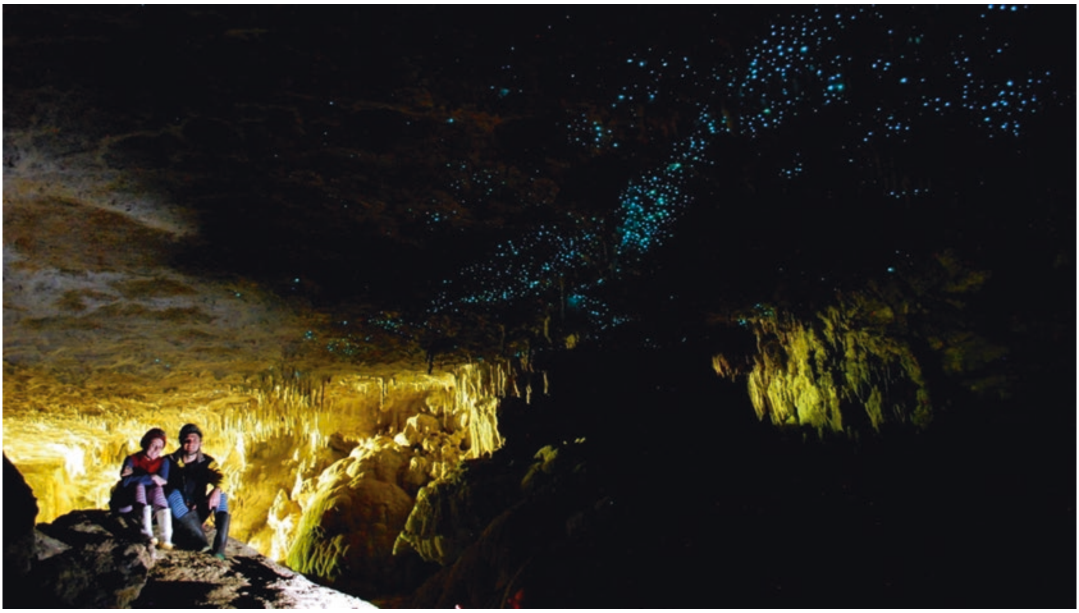

Fig. 12.10 Green Glow Caves, New Zealand. With kind permission from photographer Donnie Ray Jones

sanctuaries are not open to general access for cavers. Each Sanctuary is delineated by a string line across the passage clearly indicating to cavers that further access is barred and there is an explanatory sign. Route markers were installed to protect sensitive habitats, and there was an installation of a gate in Arthur Folly's Cave and the provision of a permit system.

The use of external cave gates to restrict public access is a common management technique for bat conservation, and an internal cave gating system was used in eastern Oklahoma (Martin et al. 2000). However, cave gating can also impede bat access to caves, and early attempts from the 1950s to 1970s often resulted in abandonment (Tuttle 1977). Gates that are more "bat friendly" have since been designed (see Fig. 12.6B). Berthinussen et al. (2017) suggested that cave gates should be used to restrict public access, although there is some evidence that no increase in bat populations always occurred.

The US NPS has allowed the viewing of the dusk departure and dawn return of a large colony of *Tadarida brasiliensis* bats from an amphitheatre at the entrance of Carlsbad Caverns (New Mexico) but has banned the use of flash photography because of concerns that it disturbs the bats.

12.4.20 Artificial Bat Caves

These have been built to try and fight WNS. The Nature Conservancy in Tennessee have embarked on a radical scheme by building an artificial cave next to an existing natural bat cave (Bellamy Cave). It began construction in August 2012 but by 2017 bats have not hibernated in it in large numbers, although researchers suggest that it can take years for bats to choose a new hibernation location. In Bellamy Cave 40,000–50,000 bats used the cave but after the Nature Conservancy bought the site in 2006 and fenced it, the numbers rocketed to 60,000 in 2010 and 265,000 in 2017, but WNS has recently been found here. Recent research projects which may well prove an answer to the syndrome are the testing of chlorine dioxide, an environmental cleaning agent which may be used to clean man-made hibernating sites such as mines; testing the effectiveness of a natural biopolymer, chitosan, to cure the threatened bats and to test the safety and effectiveness of two antimicrobial and enzyme inhibitors on the affected bats. A further artificial cave has been built at Selah, Bamberger Ranch Preserve (Bronco County, Texas), which has been a success, and over 156,000 Mexican free-tailed bats were counted in May 2011.

The mission of the WCS (Wildlife Conservation Society, Canada) BatCaver programme is to identify and study bat hibernation sites in Western Canada using the resources of cavers and the public to expand knowledge. This information is crucial to conserving bat populations from threats to their survival, such as WNS. In 2017 the organisation produced brochures aimed at people who are visiting caves which explains the risks of inadvertently transporting WNS spores from one region to another. It also contains conservation messaging, decontamination protocols for WNS, and contacts for further information. The brochures have been sent to tourist caves in Western Canada and caving organisations. They have also produced signage regarding bat conservation messaging intended for posting at bat cave entrances and a sign, after consultation with British Columbia Parks, for posting at trailheads to provincial parks.

12.4.21 Management of Lampenflora in Show Caves

Lampenflora is a problem in show caves and particularly when it becomes covered in $CaCO_3$, and such an amorphous mix of dead phototrophs and $CaCO_3$ irreversibly destroys the speleothem's natural heritage and other cultural artefacts, like prehistoric cave paintings. The simplest solution to the problem would be the complete removal of existing phototrophic communities, getting rid of the lights, and the abolition of tourist visits, but this would not be acceptable to cave management. The methods to try and counteract the problems caused by lampenflora are reviewed by Mulec and Kosi (2009) and Cigna (2011), but there is no easy solution. The physical methods include the cleaning of the speleothems overgrown by algae with brushes and water, but this is not recommended because the infestation can be more easily spread throughout the cave, there can be damage to the speleothems, and small fragile flowstones are easily destroyed. Lighting should be shut down when not needed by automatic switches as it has been estimated that the lampenflora cannot develop to any great extent where the illumination does not exceed 100/h/year. Switching off lamps for a prolonged period, for example, one month, counteracts the proliferation of phototrophic organisms. However, this may favour the diffusion of species which are especially resilient like *Phormidium autumnale* and generally cyanobacteria by reducing competition (Montechiano and Giordano 2006). The reduction in light intensity and the use of special lamps that emit light at wavelengths which do not support maximum absorption of the main photosynthetic pigments should help. UV lamps should be switched on when visitors are absent. In Mammoth Cave (USA), light-emitting diodes have controlled the lampenflora, using yellow-light LEDs at an intensity of 49.5 lux, preventing growth for 1.5 years after complete lampenflora removal (Olson 2002).

Any chemical methods for removal must have minimal side effects on the cave environment and its organisms, and biocides used should have long-lasting effects without any negative influence on the rock, the speleothems, and the electrical installations. No herbicides should be used as they are toxic to the cave environment. The possible chemical methods that could be used have been evaluated by Mulec and Kosi (2009). There seems to be no ideal solution but hydrogen peroxide, 15% by volume, was thought to be best. Meyer et al. (2017) from research at Crystal Cave, Sequoia National Park (California), evaluated various treatments of sodium hypochlorite and decided that 0.5% by volume achieved management goals for eradication of lampenflora, with limited impacts to the presence or diet of a common cave-adapted indicator species, cave springtail (*Tomocerus celsus*).

12.5 Education

12.5.1 Cave Conservation and Responsible Caving Practices

There are several important educational provisions that have been developed here by most of the national caving organisations. These include Conservation Codes and there have also been developed general Cave Conservation Codes and National Cave Conservation Policies which have a role to play in educating cavers.

(a) *Cave Conservation Code, Cave Conservation Handbook, and Protect Our Caves* from the NCA, although the BCA took over its functions in 2006.
(b) *Minimal Impact Caving Code* (1995) from the Australian Speleological Federation where the message is cave softly and Cave SAFE and Low Impact Caving from the Tasmanian Parks and Wildlife Service, the *Speleological Union of Ireland Conservation and Access Policy*, the *Caving Care Code* published by the Department of Conservation, Te Papa Atawhai (New Zealand), and the *Minimal Impact Guidelines* from the BCA (2017).
(c) *A Guide to Responsible Caving* published by the National Speleological Society (2009).

    The NCA, the British Cave Research Association (BCRA), and the Speleological Union of Ireland are constantly trying to enforce the following objectives to make the cave environment a better place: a more detailed documentation of features of particular importance and vulnerability within cave systems; the establishment of special designation for particular features, for example, voluntary special conservation areas; and joint management groups for caves requiring special conservation, with the objective of setting up a management plan.
(d) The BCRA holds a conference each year about the ecological impact of caving called the "Hidden Earth" which brings the most recent developments to the caving community. *Descent*, the British national caver's magazine also covers environmental, ecological, and research aspects of the speleological world.
(e) The US NPS has a comprehensive website that provides information to the general public, teachers, and scientific readers. The role of the NPS Cave and Karst Program in the management of caves and karst is explained with the emphasis on stewardship, responsibility, science, cooperation, coordination, and education. The importance of threats to, and management of, NPS cave and karst resources are described within the broader framework of other federal agencies' cave and karst management and programmes. Various NPS units have successful outreach programmes, as well, describing the importance and protection of cave and karst areas in their park and managed within the NPS. In 1998, the NPS developed a newsletter as an avenue for NPS cave and karst managers to share ideas about the management of cave and karst resources which is called the *NPS Cave and Karst Outreach Inside Earth Newsletter*, where topics discussed range from wilderness cave management to major construction within tourist caves (NPS Cave and Karst Program Website 2008).
(f) *Cave Leaders and Cave Instructors Certificate Schemes.* In Britain education in all aspects of cave conservation is covered within the NCA Local Cave Leader Assessment scheme and the Cave Instructor's Certificate. The theory and practice of cave conservation should be covered with ideas presented on the formulation of cave conservation plans. Certification is important because it should introduce newcomers to the activity in a safe manner via individuals or clubs where cave conservation can be enhanced. It is also important to introduce the non-caving public, especially children, to the importance of caves and their susceptibility to damage. Show caves have an important role to play here as well as the existing educational system, scouting, and other youth organisations. In New Zealand there is a similar graded system with currently five commonly used caving-specific qualifications. They are administered by the New Zealand Outdoor Instructors Association (NZOIA) and Skills Active Aotearoa Industry Training Organisation (Skills Active). The five qualifications are:
    - *Skills Active Cave Streamway award*: this qualification is for people who guide clients in streamway caves where single rope technique (SRT) is not required.

- *NZOIA Cave 1*: this qualification is for people who deal with clients in easier caves with short pitches that can be negotiated using ladders.
- *Skills Active SRT Cave Guide certificate*: this qualification is for people who guide clients in caves where SRT is required.
- *Skills Active Caving SRT Instruction certificate*: this qualification is for people who guide clients in the caving environment and has particular emphasis on SRT cave guiding instruction.
- *NZOIA Cave 2*: this qualification is for people who deal with clients in all aspects of caving, including SRT, and for those who organise and supervise caving programmes.

There is also a comprehensive set of guidelines for caving published aimed at instructor education (ASG Activity Safety Guidelines-Caving 2013).

(g) *National Caving Association Cave Conservation Policy 1990*:

This was developed by a joint English Nature and the NCA initiative for cave conservation. It suggested the formulation of cave conservation plans for individual sites designated as Cave Sites of Special Scientific Interest (SSSI), with cavers to devise and implement these plans; there should be area specific conservation committees to assist in the formulation and implementation and to encourage education and training around issues related to cave conservation and to commission research by setting up scientific databases and developing management and conservation techniques. In Britain there are 813 caves notified as sites of scientific interest for biological or geological reasons. This however gives limited powers as noted by Chapman (1993).

(h) *Cave Conservation Plans*: The development of Cave Conservation Plans involves a fourfold process (Glasser and Barber 1995). The plans for each Cave SSSI will be to integrate management of these caves for geology with management for wildlife. Within the plans the scientific interest should be documented, including the type of interest, the location, and the current condition. The pressures and threats to the cave should be described and recommended actions to counter these threats. The practical conservation measures to be realistically implemented should be suggested, and over time the effectiveness of the conservation should be monitored, and the deficiencies should be identified and addressed. An example of the recommendations for Knock Fell Caverns (Northern Pennines) suggested permit-only access, with control and monitoring of use; access should be restricted to experienced cavers, and the use of the cave should be stopped for novices and outdoor activity groups; access documentation should give the status of the cave, access restrictions, and the dangers; documentation, including a survey showing the normal visitor routes and the dangerous and sensitive areas, should be given; there should be some taped-off areas, baseline data collected, and continuous monitoring should take place. The scheme has taken a long time to develop, but there are now several examples of cave conservation plans like the Witches Cave Conservation Plan (2012), in the Leck Fell area of South Cumbria; the caves underlying "Gruffy Field" in Charterhouse-on-Mendip, including GB and Charterhouse Cave (2015); and Stoney Middleton and Waterways Swallet in the Peak District (2012, 2013).

12.5.2 Alternatives to Caving to Take Pressure Off the Caves

Alternatives can be suggested, such the use of mines which are safe and well regulated by the leaders (Fig. 12.11), such as the slate mines in the Machno Valley and Tanygrisiau in Snowdonia operated by GoBelow and Artificial Caves such as the one in the Belfast Adventure Centre (Northern Ireland).

The latter, designed in conjunction with an experienced caver to ensure as much authenticity as possible, features one of the biggest man-made caves ever seen and the world's largest artificial

Fig. 12.11 Swan Mine, Mendips. Photo by D. Huddart

cavern and tallest (8 m) waterfall as part of the Adventure Learning Park. It has over 200 m of tunnels and passageways and a cavern which is 9.5 m long, 4.5 m wide, and 8 m high. The three caving passages are pumped with water and terminate in a sump or egress pond which users must swim through to leave the tunnels. It uses sprayed concrete on pre-bent reinforcement cages. Despite the fact that the firm that has developed artificial caves (Entre-Prises) can produce stalagmites and stalactites, fossils and cave paintings to add interest using a polyester resin system, modular speleo-systems and sprayed concrete, with linear sections, chambers, arches, and squeezes, and the fact that the BCA has introduced many children to the activity at roadshow events using a portable artificial cave, there is no doubt that, despite some advantages, this is not real caving. However an alternative with an educational message seems a good alternative. This has been developed at The Cave at CityROCK Climbing Gym in Colorado Springs where there is realistic passage, over 50 formations, each with electronic sensors to detect when a caver bumps into the formations. These sensors beep and LEDs light up around them to teach the participants about their soft caving skills, a recorded voice tells the user to be more careful next time, and a computer tracks their score. This theoretically allows the users to learn about caving and cave conservation but whether the skills learned by the use of this modern technology can be transferred to real caves or will stop more cavers using real caves is debatable.

12.6 Cave Art Teaching and Experimental Archaeology

The most famous cave painting sites have been closed for many years as it became apparent that the visitor numbers changed the delicate natural environment and had degraded the images. Hence it was decided by Liverpool University that to teach archaeology students representational art it was best to build an artificial cave in the University's Central Teaching Laboratories. Of course students could get access to the representational art by visiting some of the purpose-built replica, tourist show caves (Fig. 12.12) in France and Spain such as the Caverne du Pont-d'Arc close to Chauvet created by national heritage agencies to cater for the desire of many thousands of tourists who want to see the images in their natural environment. However, these caves, apart from the cost of getting to them, are too well lit to convey a proper experience that

Fig. 12.12 Replica of lionesses painting from Chauvet Cave, Ardeche, in the Moravian Museum, Brno. Photo by HTO

students should have and they cannot be physically handled. Hence in 2014 in conjunction with Hangfast, a climbing wall manufacturer, an artificial cave was constructed. The wall replicates some of the better known painted caves like Lascaux, Altamira, and Gargas. The light used mimics the original lamps and students can use original materials to replicate images, like different types of animal fats, and can experience the difficulties of making brushes with animal hair and original glues and experience how these images might have been seen at the time. It allows experimental research (see Nelson et al. 2017) and is a novel approach to teaching that students respond to.

12.7 Minimum Impact Caving Techniques for Fauna Developed in Tasmania

This Minimum Impact Caving Techniques policy for fauna suggests:

- Keep to a single path throughout the cave and follow marked routes. Do not wander about the place.
- Move slowly and carefully at all times, taking care where you place your hands, feet and body, whilst looking out for small animals.
- Where possible, use routes which avoid interfering with fauna and sensitive habitats (Avoid trampling on wood and leaf litter, tree roots, or other organic material).
- Avoid trampling on riparian sediment banks—step on solid rock surfaces where possible.
- Avoid walking in pools and small water courses.
- In medium-energy and high-energy stream passages, walk in the stream bed in preference to riparian sediment banks or other fossil substrates. In low-energy streamways, try to avoid walking in the stream bed, but not if this causes greater degradation to riparian or other fossil substrates alongside.
- Avoid making loud noises or shining lights directly onto animals.
- Avoid breaking spider webs or entangling glow-worm snares.
- Do not leave any foreign material in the cave, including food scraps, human waste, or spent carbide.
- Cave softly!

Cave softly is as follows: *Cave S.A.F.E.*:

S—tread *slowly* and *softly* at all times. Take care where you place your hands and feet.

A—be *aware* of sensitive features, including fauna and their habitats. Walk carefully around waterways, tree roots, sediment banks and organic deposits (leaf litter, wood, dead animals). Look at, but do not disturb, spider webs and glow-worm threads.

F—be *fit*. Fitness enables you to move through the cave efficiently, so you can better appreciate the environment and experience. Tiredness and lack of fitness can contribute to cave degradation.

E—*experience*. Join a caving club—you can learn a lot this way.

Living on Karst Awareness has been created to educate landowners living in limestone regions of the potential sensitivities and environmental dangers associated with karst geology. It was published originally by the Cave Conservancy of the Virginias in the USA in 1997 by their editor Carol Zokaites.

Concluding Remarks

Caving inevitably causes damage to a specialised, rare, and delicate environment which once damaged will never recover. The aim is to minimise this damage, although most is unintentional. The number of cavers is relatively small but they can damage caves in many ways, and it is not just the geological environment which can suffer change by caving as an activity but cave fauna and flora is highly specialised, often endemic to restricted areas and they live in different cave zones. Bats are an important cave species, and they have been suffering in North America from WNS, partly spread by cavers. There are many potential management strategies for caves which include the compilation of cave plans, conservation codes, and National Conservation policies. Controlling access can be important, and there are access agreements, zero, restricted or periodic access, booking systems, gating, sacrificial caves, zoning in caves, cave exploration policies, and cave fauna management, including the building of artificial bat caves. Education for cavers includes provisions including minimal impact codes, websites, leader and instructor schemes, involvement in cave conservation planning and cave adoption schemes, and the provision of alternatives to caving, such as the use of mines and artificial caves.

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